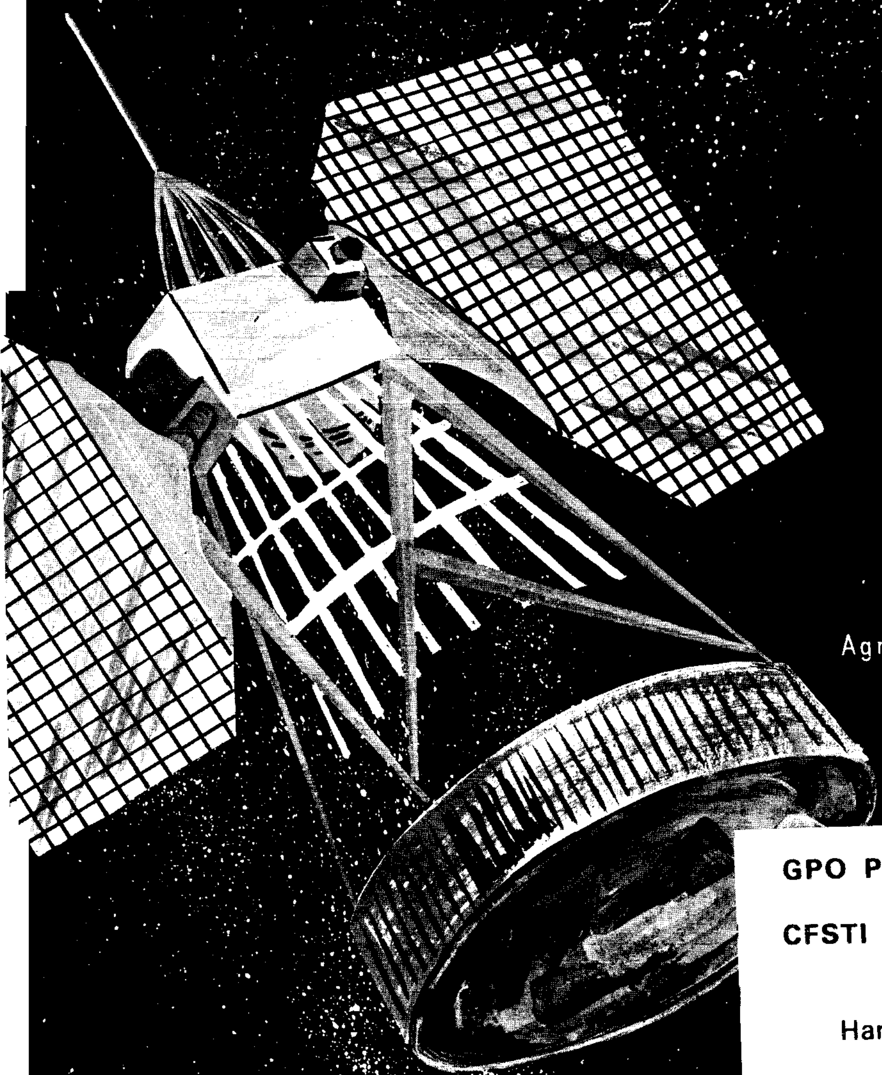

AGRICULTURAL APPLICATION of REMOTE SENSING-- THE POTENTIAL from SPACE PLATFORMS

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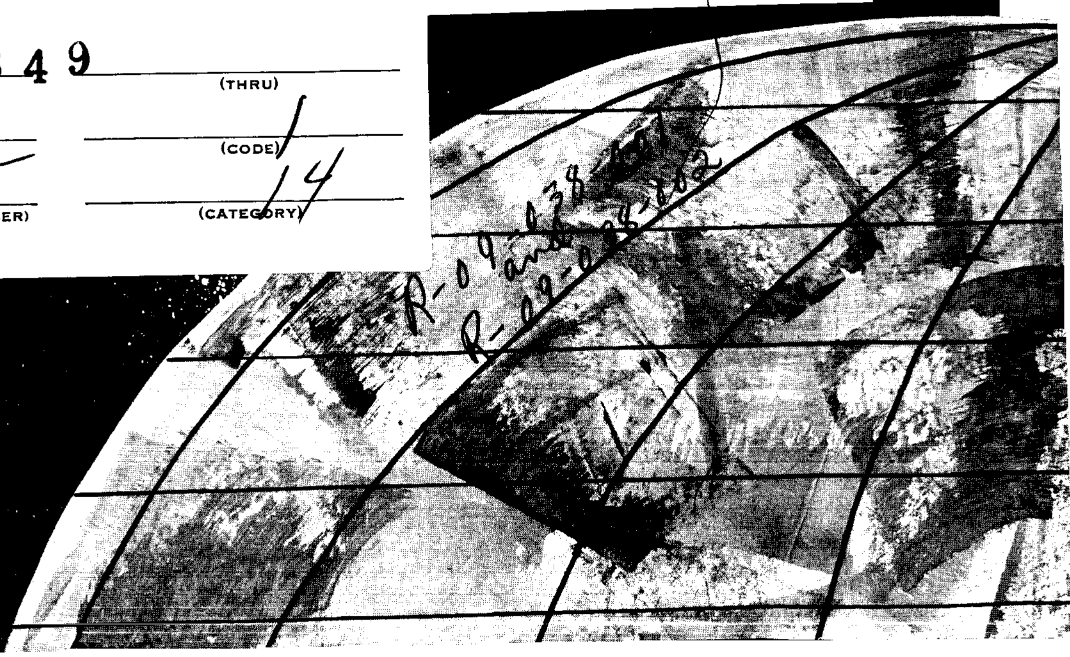

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PREFACE

Man's recently acquired ability to place instrument-carrying vehicles in orbit around the earth provides a new vantage point for remotely "sensing" the earth's surface and near-surface environment. Cameras mounted on aircraft platforms have long been used to observe a variety of natural and cultural phenomena, and a new series of related remote-sensing devices is now becoming available for this purpose. If installed in earth-orbiting satellites, these instruments can repeatedly record objects and conditions with synoptic qualities not heretofore obtainable.

The prospects for obtaining large quantities of useful data by remote sensing from space platforms have motivated geologists, geographers, oceanographers, meteorologists, hydrologists, foresters, agriculturists, and others to search for potential applications of this new technology relating to their respective disciplines. Much of their work is being sponsored by the National Aeronautics and Space Administration, which has the broader purpose of developing peaceful uses of earth satellites for the benefit of mankind.

This study identifies potential agricultural applications of remote sensing from space platforms. It was conducted as part of a more comprehensive Economic Research Service study, now in progress, to estimate the potential economic benefits to agriculture of remote sensing from orbiting spacecraft. The overall study is being conducted for the National Aeronautics and Space Administration under Interagency Fund Transfer No. R-09-038-001.

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Washington, D.C. September 1967

SUMMARY

Remote sensing from orbiting satellites is certain to yield considerable quantities of agricultural data. Existing photographic sensors, as well as photo interpretation techniques, are sufficiently advanced to perform a variety of agricultural survey tasks from space altitudes, including reconnaissance surveys of major land uses, soils, water resources, range conditions, and cropping practices. Satellite photography will also be suitable for mapping numerous objects and conditions on the ground.

Further development of photographic methods and, more particularly, of interpretation methods for nonphotographic sensors (sensitive in the infrared and microwave regions of the electromagnetic spectrum) may lead to additional agricultural application of remote sensing from space altitudes. Identification of crop species, analysis of crop vigor, and usable estimates of crop production are possibly feasible operations from space. Certain agricultural data--for detailed soil surveys and censuses of livestock--appear to be unattainable from space.

Three major factors govern the potential for agricultural surveys from space altitudes: sensor resolution capabilities, data interpretation capabilities, and informational objectives (that is, the specific data requirements of a particular survey). Of the major sensor types--camera, infrared, radar--the camera has been developed to the highest state of perfection. In comparison with other types, cameras have higher resolution capabilities and superior metric qualities. However, high resolution and wide-area coverage are conflicting goals in remote sensing. In order to keep wide-area coverage, one of the main advantages of satellite reconnaissance, cameras (as well as other sensor types) cannot be designed to maximize resolution.

Visual photographic interpretation techniques are well developed. Nonphotographic image interpretation capabilities are limited at present, but research on electronic techniques for interpreting both photographic and nonphotographic imagery is in progress. Currently, nonphotographic sensors are most valuable when used, often simultaneously, to supplement photographic sensors; they provide additional information on energy emissions not available from photographs alone.

Agriculturists in the United States have used conventional aerial photography (extensively as a base for mapping and less extensively for interpretational studies) in surveys of land use and land capability. Traditional photographic techniques are being expanded with specialized imagery. Experiments with color, color infrared, and infrared, as well as panchromatic films, particularly when exposed simultaneously and used in concert, have resulted in improved techniques for identifying crop species and analyzing crop vigor and health. Experiments with infrared photography indicate that this method can aid materially in evaluating crop response to fertilizer, insecticides, and

pesticides, and in detecting and delineating weed and disease growth. In several cases, a disease pattern appeared on infrared photography before it could be detected visually.

Multispectral sensing, a remote sensing technique involving both photographic and nonphotographic sensors, is being developed to see if distinctive spectral "signatures" can be discovered for only slightly dissimilar objects in the agricultural environment. No significant breakthrough has occurred yet, but researchers remain optimistic. Also, research is being conducted to determine and extend the utility of radar for agricultural surveying purposes.

AGRICULTURAL APPLICATION OF REMOTE SENSING--THE POTENTIAL FROM SPACE PLATFORMS

By

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Natural Resource Economics Division
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INTRODUCTION

This study intends to identify low-altitude agricultural applications of remote sensing, 1/ including those emerging from current research which appear to be technically feasible from space altitudes. Since operational experience with agricultural remote sensing from spacecraft is negligible, the appraisal of technical feasibility must necessarily be based upon the evidence of existing remote sensing capabilities and the experience and judgment of scientists familiar with low-altitude remote sensing capabilities.

The procedure used to identify potential agricultural applications of satellite data involved two basic steps. First, the maximum range of potential applications, defined as those possible or emerging as possible at low altitudes, was established by a review of the literature and research in progress. Especially noted were the objectives, methods, and results of distinctive applications and experiments.

The next step consisted of narrowing the range of potential applications to those regarded as realistically achievable from space platforms. The technical feasibility of conducting agricultural surveys from space altitudes was estimated on the basis of the evident extent to which physical phenomena can be identified and measured. Thus, particular attention was given to the resolution requirements for individual agricultural applications, in relation to the indicated and theoretical resolving capabilities of remote sensors and to existing and potential image interpretation capabilities.

1/ The term "remote sensing" as used in this report refers to the imaging or recording of physical phenomena at a distance by detecting the radiant energy which the phenomena either reflect or emit. Thus, the very broad term is used in a restricted sense to include only those remote sensing activities which involve the detection of energy characteristically moving at the velocity of light.

Remote sensing in the form of aerial photography is extensively used by agriculturists in the United States. Principal users in the U.S. Department of Agriculture are the Agricultural Stabilization and Conservation Service (ASCS), Soil Conservation Service (SCS), Forest Service (FS), Statistical Reporting Service (SRS), and Economic Research Service (ERS). In addition, the Bureau of Land Management (BLM), U.S. Department of the Interior, makes extensive use of photos. 2/

These agencies use aerial photography primarily as aids in various land resource and land use surveys conducted in connection with larger program or research objectives. As a rule, the agencies differ in type and form of data needed. Accordingly, the surveys vary in frequency, areal scope, intensity, and methodology. In general, however, the objective has been to classify, map, and measure vegetation, soils, or land use, either broadly or in detail. The observation of salient terrain features is a part of most surveys, but these features usually are not mapped or measured per se. The major elements of these surveys are shown in table 1.

Purpose, Frequency, and Areal Scope

ASCS is the principal user of aerial photography, in their production adjustment and land use programs. In these programs, designed to maintain a crop production and land use balance between supply and demand and to divert land currently not needed for production to conservation and recreational uses, the ASCS annually measures the acreage and determines the crop use of fields totaling some 200 million acres. 3/ While not all farms, fields, or crops are encompassed by the program, widely distributed crops such as corn, wheat, cotton, tobacco, and rice are included, in effect making the program nationwide in scope.

The SCS utilizes aerial photographs in major programs for the conservation and wise use of the Nation's land resources. These programs include farm conservation planning (determining land capability, recommending conserving land uses and practices, and assisting the farm operator in effecting the plan), the watershed protection program (seeking the prevention and control of floods, erosion, and other problems associated with rapid runoff of water) and the soils mapping program (supporting the above activities and serving general purposes as well). The agency maps the soils of some 50 million acres annually (54).

2/ Numerous Federal agencies, university researchers, and others have used aerial photography in solving agricultural survey problems. The minor applications are omitted in this discussion, as they differ little in their essential nature from the major applications.

Virtually all agricultural applications of aerial photography in the United States have been identified and briefly described by Steiner (49). Underscored numbers in parentheses refer to the Bibliography, p. 24.

3/ Personal communication from K. P. Harris, Deputy Director, Aerial Photography Division, ASCS, and Coordinator of Aerial Photography for the U.S. Department of Agriculture, April 28, 1965.

Table 1.--Major agricultural applications of aerial photography 1/

User 2/	Application or program	Frequency of survey 3/	Areal scope 4/ (mil. acres)	Method of data acquisition 5/	Nature of acquired data
Agricultural Stabilization and Conservation Service	Crop and land use measurement	Annually	200	Field mapping	Crop area data by farm and field
Soil Conservation Service	Soils classification and mapping	Continuing	50	Field mapping	Detailed soils map
	Farm conservation planning	Continuing	-	Field mapping	Land capability-use map; area data for individual farms
	Watershed protection	Irregular	-	Field mapping	Land use area data by flood frequency zones
	Conservation needs inventory	One survey	-	Field mapping	Land capability-use area data by sample segment
Statistical Reporting Service	Crop production estimation	Annually	Limited	Field mapping	Crop and other area data by sample segment
Forest Service	Range resources inventory	Continuing	-	Interpretation-field mapping	Carrying capacity (physical resources) map
Economic Research Service	Various economic studies	Irregular	Limited	Interpretation	Current and historical land use data (often comparative area data)
	Land use mapping	One survey	1,902	Interpretation	Generalized map of major land uses
Bureau of Land Management 6/	Range resources inventory	Continuing	-	Interpretation-field mapping	Carrying capacity (physical resources) map

1/ Numerous relatively minor agricultural applications of aerial photography, omitted here, are characterized by essentially the same elements.

2/ Agencies of the U.S. Department of Agriculture, except as noted.

3/ Frequency of field survey, rather than frequency of image acquisition, which normally is at intervals of 6 years or more.

4/ For continuing and recurring surveys, the area surveyed annually.

5/ Field mapping normally involves on-site identification of objects and conditions as opposed to the photo interpretation method in which meaning is attributed directly to photographed detail. Aerial photographs as used in field mapping serve primarily to establish and depict the spatial characteristics and relationships of the detail in the area being mapped.

6/ Agency of the U.S. Department of the Interior.

The SCS also made extensive use of aerial photographs in the National Inventory of Conservation Needs (NICN), an interagency survey conducted in 1957-59 to map U.S. land capability and use. Designations were made on sample plots on aerial photographic bases to provide a 2-percent area sample. A similar inventory is currently underway and scheduled for completion in 1967.

The FS and BLM are responsible for managing large acreages of Federally owned land, mainly in the national forests and the public domain. In 1964, the area administered by these agencies in the 48 contiguous States totaled more than 340 million acres (53). Extensive portions of this land are usable for livestock grazing and are made available to private ranchers for this purpose. Both administering agencies utilize aerial photography in continuing or periodic surveys of the rangeland that is under their supervision to obtain information on its livestock-carrying capacity.

Among the activities of the SRS, which serves as the main fact-finding agency of the U.S. Department of Agriculture, are annual nationwide crop and livestock surveys. Aerial photographs as substitutes for conventional maps play an important role in these surveys, although only relatively few photographs are required since the surveys are conducted on a sample basis.

The ERS uses aerial photography in special cases to obtain necessary information on land use for its economic research program. The areal scope of ERS surveys is normally on the order of a few townships or counties, but in one instance an extensive survey of land use was conducted in all 48 contiguous States.

Characteristics of Conventional Photography

Most aerial photography used in U.S. agriculture is collected to the same specifications in terms of scale, film, filter, camera focal length, and format. This uniformity occurs primarily because a high proportion of the photographs is procured by the ASCS for their purposes and then made available to other users. With minor exceptions, ASCS photographs are taken at a vertical angle (maximum departure of 4 degrees) on panchromatic film with a minus-blue filter at the contact scale of 1:20,000. With a camera having a focal length of 8 1/4 inches, exposures are made on 9" x 9" film format and spaced to provide sufficient overlap for stereoscopic viewing. Photographic surveys are conducted without regard to season, except that the ground must be free of snow, standing water, etc., but surveys are limited to time of high sun angle on cloud-free days. The resolution achieved is approximately 20 lines per millimeter at the center of the field (52).

Photography procured by ASCS covers approximately 80 percent of the total area of the 48 contiguous States and Hawaii and virtually all of the Nation's cropland. Most areas have been photographed three or four times since the late 1930's in an acquisition program designed to periodically update areas undergoing change. Limited quantities of comparable photography are procured by the SCS and FS when their needs are not met the ASCS procurement programs.

Method of Data Acquisition

The aerial photography described above provides an overview of a portion of the earth's surface in which a wealth of pictorial detail is recorded in approximately correct spatial relationship. Even if all photographic detail cannot be fully interpreted, the photographs provide orientation for boundary delineation. To the extent that photographic detail can be interpreted, large areas are figuratively brought to the office for study.

Three methods of data acquisition from commonly available aerial photography have been developed by U.S. agriculturists: field mapping, photo interpretation, and stereoscopic photo interpretation. The most widely used method of data acquisition is field mapping--the identification and mapping of detail on the ground using photography as the mapping base. This is the principal method used by ASCS, SCS, and SRS.

In the ASCS and SRS applications, field boundaries and crops are delineated and labelled on photographic enlargements by an on-site observer and subsequently measured by planimeter. Photo interpretation is precluded by the lack of timeliness and also by the scarcity of crop identification characteristics on the photography. Geometric outlines on the photographs, in terms of field lines, roads, topography, natural vegetation, etc., remain relatively accurate for several years, however, and provide the framework for mapping and area measurement. Changes in these features are made as necessary by applying appropriate markings and notations on the photography during the course of the ground survey.

Soil classification and mapping are performed to varying degrees of accuracy and precision. Reconnaissance surveys can be largely accomplished by photo interpretation, as gross soil properties and characteristics are indicated by easily recognized features of the terrain and natural vegetation. However, most soils surveys in the United States are quite detailed. The method used by SCS to map soils in detail is based primarily on field observation but includes stereoscopic photo interpretation in the survey planning stage and for numerous tentative identifications (48). After the soil-type boundaries are located on the ground, they are delineated on photographic enlargements. The considerable detail recorded on the photographs provides orientation and reference points for the field mapper.

The field mapping method is also used by SCS to obtain data on land capability and land use for its various conservation activities. However, stereoscopic photo interpretation may have special application in some instances. In flood control surveys, for example, the delineation of flood-frequency zones is accomplished by plotting marks of past floods as identified by field observation on the photographs and connecting them stereoscopically (48).

Methods of conducting range resources surveys vary slightly in detail between and within the FS and BLM. In general, both agencies rely heavily on a joint photo interpretation-field mapping procedure. Photo interpretation is employed to map major vegetation types, terrain features forming natural boundaries or barriers to livestock movement, and water resources. Distinctive but unidentifiable patterns are also delineated on the photographs in the photo interpretation phase, as the patterns usually coincide with boundaries between areas of different vegetative type and density.

Additional information is obtained in ground surveys. Interpreted delineations on aerial photographs are revised and annotated to reflect forage type and density, improvements, areas needing reseeding, and areas susceptible to erosion or containing noxious weeds. Typical survey procedures have been described by Henriques (23).

Stereoscopic photo interpretation with little or no field work has been used in several ERS land use studies. This method has yielded useful data on cropland, pastureland, forestland, land clearing and drainage, potential recreation sites, transportation areas, urban areas, individual buildings, and water areas. An important feature of most of these studies has been the comparisons of photographs taken at different points in time to measure changes in land use. A description of the comparison method of photo interpretation, with reference to ERS land use studies, has been provided by Dill (17).

The Bureau of Agricultural Economics, predecessor to ERS, prepared a 1:5,000,000 scale map of the 48 contiguous States, based on photo interpretation, showing 13 classes or associations of land use and natural vegetation. In this case, small-scale photo mosaics were interpreted on a county-by-county basis. Actually, the mapping problem was not so much one of interpretation (much information on the nature and location of land uses was available) as one of locating boundaries between classes with greater geographic precision than had previously been achieved with other methods. The map, entitled "Major Land Uses in the United States" (now out of print), was compiled in 1950 by F. J. Marschner.

Type and Form of Data

Although aerial photography generally serves diverse purposes for conventional agricultural applications, most such photographic data relate to either land use or land capability. The ASCS and SRS crop identification and measurement activities and the ERS economic studies yield quantitative data on crops, cropland, urban land, and other land uses. In contrast, range resources inventories and soil surveys result in qualitative data on natural features and conditions affecting potential land use. Often, both types of data are obtained in the various conservation activities of SCS.

Aerial photographic data obtained for agricultural applications, with minor exceptions such as individual object counts, are initially mapped on the photographs. The final product may be either area data in statistical form, distributional data in map form, or both. The production adjustment and land use programs, crop and livestock surveys, and economic studies all require area data on particular land uses. The mapping step normally is only a means to an end. Range resources inventories and soil surveys emphasize the distributional aspects of soils and range resources, but not to the exclusion of area data. The final product may be either (1) a photo mosaic with linework and annotations added, as presented in all recent soils survey reports, or (2) a planimetric map. Both permit generation of area data as desired. Land capability-use maps and area data derived therefrom often are developed and used jointly in flood control surveys, farm conservation planning, and related activities.

Advantages of Aerial Photography

Aerial photographic methods for agricultural objectives offer advantages over the alternatives--mainly ground surveys. The two especially valuable assets of aerial photography are the essentially correct geometry and abundant pictorial detail, which in mapping activities make unnecessary much of the preliminary task of developing horizontal control by ground traverse. The detail in aerial photography facilitates the survey process by providing more orientation points than cartographic presentations.

Consistency and reliability of data are often improved by using photography. The enumerative crop surveys of SRS, for example, are conducted on a sample basis in which small errors in crop acreages would be multiplied many times in expansion. Map coverage of the sample segments varies from standard topographic maps to county highway maps. These maps differ, of course, in detail depicted and geometric fidelity. Thus, air photographs serving as segment and farm maps provide superior data in this application.

Aerial photography also provides a means of obtaining timely data not available from scheduled ground surveys. The census of agriculture gathers information on crop species, acreage, and other data at 5-year intervals and publishes it by counties. These data are not adequate for crop production estimates and other purposes which require precisely located annual data. The comparative photo interpretation studies of ERS yield historical land use data not otherwise obtainable. These data reveal the nature and extent of change by precise geographic location, while traditional historical statistics show only overall net changes for an area.

The advantages of aerial photography mentioned above are not exhaustive but are illustrative of the economies in time, effort, and cost. Some of these advantages, as well as others, have been discussed with partially different emphasis in an article by Dill (18).

AGRICULTURAL REMOTE SENSING RESEARCH

Aerial photography in agriculture would be considerably more valuable if crop species, crop and range conditions, soil types, and livestock could be accurately and consistently identified. Data of these types would have potential application in surveys of agricultural production and production potential and in the control of crop diseases, noxious plants, and insects. The potential agricultural value of specialized aerial photography, as well as the more limited value of conventional aerial photography, has been recognized in several current or recently completed experiments concerned with the development of sensor image specifications and interpretation techniques (table 2). Some of the findings have had limited local application.

Experiments with Panchromatic Photography

Crop species identification is required for the production adjustment and land use programs and in crop yield prediction. Accordingly, several researchers have investigated the possibilities of using panchromatic photographs for

Table 2.--Experiments with remote sensing in agriculture

Investigator	Imagery		Subject
	Type	Scale	
Wright	Multiband photography	1:12,000 and larger	Identification of crops and cropping practices
Clair Hill & Associates 1/	Infrared photography	1:24,000	Crop identification and mapping
Goodman	Panchromatic photography	1:5,000	Crop identification
Steiner	Panchromatic photography	1:20,000	Crop identification; pasture classification
Brunnschweiler	Panchromatic photography	1:13,000	Crop identification
Colwell	Multiband photography	1:10,000 to 1:2,000	Crop identification; disease detection
Charter	Infrared photography	1:5,000	Plant stress analysis; yield prediction
Brenchley & Dadd	Infrared photography	1:12,000	Disease detection
Manzer & Cooper	Infrared photography	Large	Disease detection
Crop & Livestock Reporting Service (Calif.) 1/	Panchromatic photography	1:17,000	Crop production estimation
Colwell	Multiband photography	1:20,000 to 1:2,000	Range conditions appraisal
Colwell	Multispectral imagery	Large	Crop and livestock identification
Holter & Shay	Multispectral imagery	Large	Identification of crop species and soil properties; crop vigor analysis
Myers	Multispectral imagery	Large	Measurement of soil moisture and salinity
Simonett, et al	Radar	Large	Vegetation and soils classification

1/ Limited operational application

this purpose. In a 1959 report excerpted from her doctoral dissertation, Goodman (21) described a technique for identifying crops on panchromatic photography. The technique primarily takes advantage of the principle that in crop growth an optimum stage exists for distinguishing on aerial photography among the several crops in any agricultural area.

The study area consisted of 13 square miles in northeast Illinois, which was photographed at the scale of 1:5,000 on nine separate occasions over the growing season. Analysis of the photographs indicated that corn, soybeans, wheat, oats, barley and hay are identifiable by their tonal and textual qualities and by associated objects such as farm implements, lanes, and haystacks. The textual qualities and associated objects were evaluated with a stereoscope for crop identification clues, while tonal qualities were measured with a densitometer. Other findings showed that (1) photographs taken during the second half of July provided optimum criteria for crop differentation in the study area, and (2) variations in physical conditions and farm practices had little effect on the photographic appearance of crops.

The pictorial variations of the agricultural landscape over the seasons, as recorded on panchromatic film, also have been objects of studies in Switzerland. Brunnschweiler (5) analyzed seven sets of photographs taken during the course of 1 year at the scale of 1:13,000 covering a small area in the vicinity of Zurich. Units for interpretation included cropped fields, pasture, and forest. The study concluded that most crops and all land use types in the environment studied exhibit specific pictorial characteristics which relate to time of year and which can be identified by tone, texture, and stereoscopic appearance on a properly spaced series of panchromatic photographs at the scale employed.

Steiner (3, pp. 594-599) compared two series of panchromatic photographs of an alpine area in the canton of Grisons characterized by the classic agricultural practice of transhumance; one series was taken in early June 1941 and the other in late June and August 1954. Among the significant findings was the striking difference between improved and unimproved meadows that is visible on photographs taken in early June. At this time, the advanced growth of improved meadows, relative to that of unimproved meadows, is reflected in plant color and consequently in photographic tone. Crops were identified on photographs at the relatively small scale of 1:20,000. Potatoes were distinguishable, as were, in most cases, the individual species of small grains. The study concluded that sequential photography taken at proper stages of crop growth but in different years is adequate for carrying out a nearly complete land use interpretation in areas where the vegetative cover changes only slightly from year to year.

Currently, the California Crop and Livestock Reporting Service successfully uses aerial panchromatic photography to estimate accumulative raisin production as the harvest season advances. The raisin area, consisting of some 800 square miles centered near Fresno, is photographed approximately seven times at a 1:17,000 scale with a panoramic system during the harvest season of about 6 weeks. Although complete photographic coverage is obtained in these missions, a sampling procedure is used to estimate the portion harvested for raisins of the total known grape acreage. Dots superimposed over sample plots on master photographs taken during the first survey of the season are observed on succeeding operational film to determine whether or not they fall in areas where grapes are drying on trays to form raisins. An indication of yield is obtained by (1) tray counts on the photographs and (2) ground visits on a subsample basis to weigh and count the number of trays in specified areas. This unique application of aerial photography has considerable economic significance, since growers must decide at what point the anticipated market demand for raisins has been satisfied. When this condition has been met, the remaining grape harvest can be more profitably diverted to wine production (42).

Panchromatic aerial photographs also yield information on the flooding of agricultural land. Timely photography taken as a flood threat develops may support decisions on precautionary measures. Photographs taken while an area is being flooded will indicate where rescue efforts should be directed. Photographic coverage as flood waters recede records damage to crops, soil, and facilities. If taken periodically during the flood, photos permit accurate estimates of the period that crops have been inundated and, consequently, can be the basis for estimates of the probable crop mortality or yield reduction from this cause (3, pp. 615-624). The SCS has also used photos in developing maps of flood-prone areas and for establishing flood stage-area relationships.

Experiments with Infrared Photography

Imagery formed by sensing in the transitional zone between the visible and infrared regions of the spectrum (photographic or near infrared) has added a new dimension to the use of aerial photography in agriculture. Various researchers have found it particularly useful in defining areas of vegetation stress. According to Charter (6), infrared photography of 1:20,000 scale and larger provides information that can aid materially in evaluating crop response to fertilizer, insecticides, and pesticides, and in detecting and delineating weed and disease infestations. Its utility at 1:5,000 scale was illustrated by a case in which a diseased condition (oak root rot fungus) was detected on plum trees before the condition was visible to a ground observer.

The buildup of a potato blight epidemic in the Fenland area of England has been recorded on sequential infrared photography by Brenchley and Dadd (4). The negatives, viewed over a light table, showed the disease pattern spreading at an irregular rate from one focus to numerous daughter foci and finally to epidemic proportions.

Detection of late blight and relative measurements of potato foliage damage have also been accomplished on large-scale infrared photography by Manzer and Cooper. 4/ The interpreted results from a series of infrared experiments compared favorably with disease severity ratings made by standard field methods. Similar to observations cited elsewhere in this report, late blight infection was detectable on infrared photography before it was readily apparent visually.

4/ Personal communication from F. E. Manzer, Professor of Plant Pathology, Department of Botany and Plant Pathology, University of Maine.

Infrared photography has also been used on test sites in Texas to map the extent and evaluate the severity of saline conditions associated with fluctuating water tables (39). In this experiment, cotton suffering from physiological drought as a result of saline conditions in the 1 to 4-foot soil profile was found to photograph in tones varying with the severity of saline conditions.

Clair Hill and associates, a consulting engineering firm, has employed infrared photography to map the 160,000 acre Glenn-Colusa Irrigation District in California (34). The objectives were to (1) determine the acreage of individual fields and (2) identify by photo interpretation some 60,000 acres planted with rice. The acreage determinations were needed for water billing purposes and to meet the requirements of the ASCS rice program. Infrared photography was selected for use after some experimentation since it emphasizes the appearance of water bodies. Fields flooded at the time of photographic coverage were easily spotted in the photographs, and their identification was tantamount to identifying rice itself. A scale of 1:24,000 was selected as a compromise between economy and accuracy. This photography was used in conjunction with specialized photogrammetric equipment to compile large-scale planimetric and photo maps on which field acreages were measured.

Experiments with Multiband Photography

The value of multiband photography 5/ for identifying cereal crops and certain diseases affecting such crops has been tested in a classic study by Colwell (12). His objectives were (1) to determine the aerial photographic specifications necessary for detecting and identifying certain important diseases in wheat, oats, barley, and rye, and (2) to ascertain the features by which these crops and their specified diseases might be identified on photographs taken in accordance with these specifications.

Several promising film-filter combinations were selected for the experiment on the basis of spectrophotometric analysis of light reflected from leaves of healthy and diseased cereal crops. The selected films, including panchromatic, color, infrared, and color infrared, were exposed over open fields and and carefully controlled nursery plots at several locations and under various conditions. Analysis of the photographs indicated that, by using two or three sets of photographs flown to proper specifications, it is usually possible to identify (1) healthy wheat, oats, barley, and rye, and (2) wheat and oats infested with black stem rust, and oats infested with yellow dwarf virus. In the final specifications, panchromatic and infrared photographs at scales as small as 1:20,000 had value for detecting tonal differences. Color photographs of selected points at scales as large as 1:500 might be required for accurate estimates of disease severity and resultant yield reduction. Scales specified for most of the tasks ranged between 1:2,000 and 1:10,000.

Experimenting on range herbage, Colwell has found that specialized photography will provide information not normally available from the photography employed by the FS and BLM in range surveys (10). In this case, he classified

5/ The term "multiband" refers to images formed, usually simultaneously, in more than one portion of the photographic region of the electromagnetic spectrum and analyzed jointly.

range herbage in several foothill areas of Contra Costra County, Calif., into three carrying capacity classes largely on the basis of photographic color and tone. Ground checks following the interpretation confirmed that the classification was well within acceptable accuracy limits for range surveys.

For the study, several film-filter combinations were exposed at scales between 1:2,000 and 1:20,000 during each of the four seasons, although late spring was found to be the optimum time for photographic coverage. Ektachrome film with a haze-cutting filter yielded the best results. As a cost consideration, a scale of 1:5,000 was specified, but spot coverage at larger scales was regarded as desirable.

Researchers at Cornell University, as reported by Wright and Schepis (57), investigated the utility of aerial photography in agronomic surveys. In general, the researchers were motivated by the need for a rapid and economical method of obtaining unbiased information on the nature of farming practices in New York. This study involved panchromatic photography at the scale of 1:12,000 and panchromatic, color, and infrared photography at larger scales covering a 70-mile strip in Jefferson County. With this selection of film and scales, the agronomists-interpreters were able (1) to observe how closely the farmers followed extension service advice regarding timeliness of hay harvest, (2) to explain previously observed variations in harvest dates for corn, and (3) to deduce the length of crop rotation. Other photo interpretations included identification of the major crops of the area (corn, oats, and hay) and one species of weed.

Research on the usefulness of aerial photography in livestock inventories is currently underway in California, where Colwell (8) is attempting to develop photographic specifications and interpretation techniques for enumerating livestock by species, use, breed, sex, age, and vigor. The relative merits of various film-filter combinations for these purposes have been intensively evaluated under simulated conditions. Selected combinations have also undergone limited testing at low altitudes on representative range and pasturelands. In most situations studied, the optimum aerial photographic specifications, in view of cost factors, called for panchromatic film, a Wratten 12 or 25A filter, and a scale of approximately 1:6,000.

Experiments with Nonphotographic Imagery

Researchers at several institutions are currently engaged in investigations to determine the spectral differences shown by crops, soils, and other elements of the agricultural environment when they are observed simultaneously in various portions of the nonphotographic as well as photographic region of the spectrum.6/ Among these researchers are (1) Holter, Lowe, Shay, et al, who are jointly engaged in a study involving the University of Michigan and Purdue University; (2) Colwell, et al, working on the Davis Campus of the University of California to identify both crops and livestock by multispectral remote sensing techniques; and (3) Myers, et al, working at Weslaco, Tex., on salinity and soil moisture

6/ The term "multispectral" is used hereafter to designate imagery formed, usually simultaneously, in more than one spectral region and analyzed jointly.

problems of interest to agriculturists. 7/ These research efforts are logical extensions of photographic remote sensing in which relatively gross spectral differences exhibited by natural and cultural phenomena have been differentiated with abundant success. In theory, minute spectral differences are susceptible to detection and measurement as well, particularly when these differences are sensed simultaneously at intervals over a broad portion of the spectrum and are analyzed electronically. The hope is that unique tonal "signatures" reflecting these slight spectral differences will be discovered for numerous objects and conditions in the agricultural environment.

The following account of multispectral sensing research at Michigan and Purdue Universities is based on the first progress report by Holter, Lowe, and Shay (26) and on subsequent communications from these and other members of the investigating team:

The airborne instrumentation system employed consists of two multichannel optical-mechanical scanners and several photographic cameras. One of the scanners is adjusted to detect radiant energy at intervals in the 1.5 to 5.5 micron wavelength range of the electromagnetic spectrum. Imagery formed by sensing in this range results largely from emitted rather than reflected radiation and thus can be produced day and night. The other scanner, operating in the 0.32 to 0.38 micron range (ultraviolet) and in the 1.5 to 1.7 micron range (infrared), is used only in daylight since reflected energy predominates in these ranges. The several cameras are equipped with film-filter combinations permitting operation in various bands of the visible and near-infrared regions of the spectrum. One camera contains multiple lenses and produces photographs in eight narrow bands and one broad band throughout the photographic region (0.38-.89 microns).

This system was used for observations at intervals throughout the 1964 growing season, with farms in the Purdue Experiment Station Complex at Lafayette, Ind., as test sites. Fields in this area contained all major crops and grains of the Midwest, a number of crops important outside that region, various vegetable and tree fruit crops, and conifer and hardwood trees. An abundance of target variations existed as these vegetative types represented numerous species and varieties grown under diverse conditions. The plan called for five to eight missions of six flights each, with the six flights of each mission to be spaced throughout a 24-hour period. The arrangement permitted measurement of the effects associated with crop growth, changes in sun angle, and the diurnal heating and cooling cycle. Although modified at several points, this schedule was maintained in essence. Similar observations have now been obtained during subsequent growing seasons and still other flights are planned.

Several environmental parameters expected to affect the appearance of the imagery were measured at selected sites on the ground. A portable system measured and recorded micro differences in (1) incoming and outgoing solar and long-wave radiation, (2) sensible temperatures, (3) water vapor content of the

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7/ These studies are all being conducted under research grants from the National Aeronautics and Space Administration and have significant support from other Federal agencies. A committee of the National Academy of Sciences' National Research Council is serving in an advisory capacity and individual members of the committee are performing services for the project.

air, (4) wind velocity above the vegetative canopy, (5) barometric pressure, and (6) soil moisture. These data were supplemented by conventional weather observations and Experiment Station records.

The imagery from the series of missions is currently being analyzed. No significant breakthrough which will permit rapid and consistent identification of crops has been achieved as yet, but the investigators and their advisors remain optimistic. In support of this attitude, they point out that other spectral bands remain to be investigated and that many possibilities exist for modifying or improving the instrumentation. With respect to identification of soil characteristics by spectral matching techniques, the findings to date reportedly are discouraging.

Colwell, et al (13), and Myers, et al (38), have reported on multispectral sensing research at Davis, Calif., and Weslaco, Tex., respectively. These research efforts are broadly similar to the effort at Purdue, as all three seek to determine and exploit the varied spectral responses of agricultural targets when they are observed in portions of more than one spectral region. Techniques for identifying livestock, as well as crops, are under development at Davis, while experiments at Weslaco are directed toward relative measurement of subsurface moisture and salinity conditions. The investigators at both locations are continuing previous work on these subjects involving visual interpretation of aerial photographs. Their previous efforts can be described as experimentally successful, but the supplemental use of nonphotographic imagery, particularly thermal infrared, has yielded additional information in both instances.

Another research team located at the University of Kansas is investigating the potential of radar sensors for identifying soils and vegetation. For national security reasons, the details of this work and particularly of the instrumentation are not available. The state of present development in the field has been summarized by Simonett (47), as follows:

"Studies...have shown that single radar images of the type expected from orbital radar can be useful as a tool for study of some soil distributions at the soil association level of generalization in grassland or lightly treed environments.

...preliminary study suggests that multiple polarization will add to the present capability in helping to distinguish additional soils units through variations in natural plant communities.

...other studies...have indicated that natural and cultivated vegetation change in their radar reflection characteristics with phenologic variations, and the change in radar characteristics may thus serve as a tool for identification of a plant community or crop within certain probability limits."

The report goes on to say, "Use of several polarizations raises the number of parameters available for differentiation and increases the probability of correct identification. The principle in essence is the same as multiband spectral reconnaissance, except time varying and polarization parameters constitute the information matrix."

Potential agricultural applications of satellite imagery must necessarily be identified by considering the imagery requirements for individual applications in relation to remote reconnaissance capabilities. Actually, the imagery requirements for agricultural surveys cannot be stated exactly, except in a few instances where minimum specifications have been determined experimentally to be very rigorous. Evaluation of remote reconnaissance capabilities from space altitudes must be based on particularly limited experience, since relevant satellite imagery available to date does not represent this potential. However, the question of technical feasibility can be answered satisfactorily by determining whether the minimum requirements for particular applications are either realistically within or beyond the capabilities of sensors on space platforms. The major factors governing remote reconnaissance capabilities will be considered first.

Characteristics of Remote Sensors

The array and nature of sensor types usable for agricultural reconnaissance has not been fully considered in current literature on remote sensing. These sensors--photographic, infrared, and microwave systems (including radar)--function fundamentally by recording reflected or emitted energy from physical objects or conditions. They differ primarily in that, as the names imply, each is sensitive to energy of a limited and largely nonoverlapping wavelength range within the total electromagnetic spectrum. Numerous varietal differences have appeared as a result of instrumentation design, type, and format of recording medium, etc. (table 3).

Table 3.--Advantages and disadvantages of sensor types 1/

Sensor capability	Camera	Infrared	Radar
Day/night sensitivity	5	10	10
Haze-fog penetration	3	6	10
Cloud penetration	1	2	9
Temperature discrimination	2	10	1
Subsurface detection	4	6	3
Stereo capability	10	2	3
Accurate image representation	9	6	5
Long-range capability	7	4	8
Resolution	9	7	5
Clarity or images	9	6	6
Availability of equipment	10	4	4

1/ As summarized by Leonardo (32). In the scale, poor = 0 and good = 10.

Of the three sensor types listed in table 3, photographic cameras have been developed to the highest state of perfection. In comparison with other sensor types, photographic systems possess higher resolution capabilities and superior metric qualities, and photographic interpretation techniques are relatively well developed. Nonphotographic sensors record additional reflective and emissive qualities of objects and also provide a potential day-night and all-weather sensing capability. Hence, informational gains can be expected from the joint use of two or more sensor types.

The factors affecting the ability of remote sensors to record targets are complex but relatively well known. For photographic sensors, this capability, commonly termed resolving power, is expressed in lines per millimeter (ground resolution is expressed in feet). Resolution has been defined as "the ability of a film or a lens, or a combination of both to render barely distinguishable a standard pattern consisting of black and white lines (28, p. 74)." Roughly five times better ground resolution is required for object identification than for object detection (27). Among the variables on which resolving power depend (not an exhaustive list) are sensor optics, distance from target, type and format of recording medium, strength of energy source, contrast between target and background, atmospheric conditions, and recording medium processing techniques.

The maximum theoretical resolving power (Nm) of a photographic lens may be expressed by the equation $Nm = \frac{1472 \text{ lines/mm}}{\text{f-number}}$, where f-number represents the ratio between lens aperture diameter and the focal length of the optical system (41). At a given altitude and within limits imposed by other restrictions, resolution can be increased by increasing the focal length of the optics, providing the diameter of the lens aperture is also increased sufficiently to maintain an appropriately low f-number. The following calculations by Katz (29) are approximations of the maximum ground resolution obtainable with selected focal lengths and film resolving powers at an altitude of 142 miles:

Focal Length	Resultant Scale	Ground Resolution (40 lines/mm)	Ground Resolution (100 lines/mm)
12 inches	1/750,000	60 feet	24 feet
36 inches	1/250,000	20 feet	8 feet
120 inches	1/75,000	6 feet	2.4 feet

The relationships between these calculations also illustrate that high resolution and wide-area coverage are conflicting goals in remote sensing. When focal length is increased, a corresponding decrease occurs in area coverage, since the field of view is narrowed. The decrease in area coverage, in turn, is reflected in image scale, determined as the ratio between focal length and distance (altitude). Since wide-area coverage is generally regarded as a desirable feature of satellite reconnaissance, the practical effect is a restriction on the use of huge optics to obtain high resolution.

An adequate summary of the resolving powers of nonphotographic sensors is not available. Current scientific literature, however, implies that these capabilities are somewhat less than those of photographic sensors. For example, Leonardo assigned resolution values of 9, 7, and 5 to photographic, infrared, and radar sensors, respectively, in his comparison of sensors (table 3).

Image Interpretation Capabilities

The state of the art of image interpretation is another basic consideration in evaluating the potential use of satellites for agricultural observations. Interpretation capabilities at specified resolutions have been summarized by the team of scientists responsible for managing NASA-sponsored research on remote sensing in the U.S. Department of Agriculture. 8/ The summary states:

I. At a resolution of 30 meters, we can interpret the following:
   - Timberline
   - Waterline
   - Snowline
   - Desertline
   - Grassland-brushland interface
   - Brushland-timberland interface
   - Grassland-timberland interface
   - Bare soil vs. vegetated areas and individual fields 10 acres or more in size
   - Major roads, railroads, and waterways

II. At a resolution of 10 meters, we can interpret:
   - Mature orchard trees
   - Dominant rain forest trees
   - Fields one acre or more in size
   - Farmsteads
   - Fence lines used to control grazing
   - Areas greater than 30 feet in diameter in agricultural crops where damage has been done by disease, insects, fire, storm or other agents

III. At a resolution of 2 meters, we can interpret:
   - Density of woody vegetation
   - Individual tree counts
   - Tree crown diameters
   - Species of dominant trees
   - Areas in agricultural crops greater than 2 meters in diameter that have been damaged by disease, insects, fire, and natural disaster
   - Species of continuous cover crops occupying fields greater than 20 feet square and weed patches of 20 feet square
   - Drainage patterns
   - Soil series boundaries
   - Major soil series and soil moisture differences
   - Areal extent of water surfaces
   - Mapping of planimetric detail in agricultural areas
   - On sequential photography (repetitive cover of the same area), rates of plant growth, plant succession, probable future planting plans, and probable crop yields

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8/ Unpublished statement dated March 8, 1966. Members of the Research Management Team at the time were H. A. Rodenhiser, R. N. Colwell, H. A. Steele, J. R. Shay, and R. K. Arnold.

The team's definition of existing interpretation capabilities applies primarily to photographic imagery because nonphotographic image interpretation capabilities are still poorly developed. The team's statement generally agrees with the findings elsewhere in this study, except for one significant difference. According to the team, species of continuous cover crops are identifiable with a resolution of two meters. In comparison, the large image scales specified by Colwell for cereal crop identification, as well as the reported experience of other investigators, imply that, except in special situations, resolution requirements for crop species identification are somewhat more rigorous than two meters.

In assessing potential photographic interpretation capabilities, it should be remembered that resolutions greater than two meters have been available at low altitudes and are theoretically attainable from satellite altitudes. Resolution greater than two meters has permitted a variety of ingenious image interpretations. Nevertheless, in view of the characteristically complex nature of experimental interpretation efforts, additional interpretation capabilities based on high resolution are not likely, particularly from space altitudes.

The potential for developing photographic interpretation techniques based on timely and frequent overflights is apparently substantial. Several of the reported experiments have successfully exploited seasonal changes in the agricultural landscape. The results of these experiments indicate that planting, cultivation, and harvesting practices, changes in the surface area of water bodies, and even crop species, to name a few possibilities, are to some degree identifiable and measureable by frequent observation at space altitudes.

Electronic interpretation of photographic imagery is another possibility. In general, the status and prospects for interpreting photographic imagery electronically are identical to those for nonphotographic imagery (discussed below).

Although nonphotographic interpretation abilities are limited at present, the potential appears most promising. The supplemental use of sensors sensitive in nonvisual regions of the electromagnetic spectrum is expected to provide a vantage point not afforded by the visible region alone for recording physical objects and conditions. Informational gains may result from either additional observations of previously photographed object characteristics or original observations of additional object characteristics. Interpretation normally must be accomplished electronically because of the large quantity and variety of data generated in multispectral sensing. Devices for this task are in the research and development stage.

Informational Objectives

The informational objective is a fundamental factor governing the use of remote sensors in agricultural surveys. Some data types are not susceptible to remote sensing. Even if the data type of interest is inherently susceptible to remote reconnaissance, the necessary detail, form, completeness, and accuracy will depend upon the purpose to be served. Reported experience has shown that imagery specifications must be carefully developed for individual surveys in order to accomplish specific objectives.

The variety of data objectives attained experimentally suggests that, from the technical standpoint, most survey requirements can be satisfied at low altitudes by the use of specialized imagery. Thus, it is reasonable to expect that similar adaptations of satellite imagery will frequently be possible; it does not necessarily follow, however, that the same adaptation possibilities exist for imagery taken at space altitudes.

Obviously, the detailed data objectives of potential agricultural surveys from space platforms cannot be fully determined. Thus, potential applications can best be identified as broad categories reflecting distinctive but general objectives.

POTENTIAL AGRICULTURAL APPLICATIONS OF SATELLITE OBSERVATIONS

Designations of (1) feasible, (2) possibly feasible, and (3) infeasible at space altitudes can now be applied with reasonable confidence to low-altitude applications (defined as broad "application areas") of remote sensing. Essentially, application areas are regarded as feasible if the resolution requirements for usable data are not rigorous and interpretation techniques are well developed. At the other extreme, application areas are regarded as infeasible if the resolution requirements are very rigorous and interpretation capabilities have not been developed. The remaining application areas, where resolution capabilities appear to be adequate but interpretation capabilities have not been developed, are classified as possibly feasible. In the only significant departures from these rules, surveys of range conditions and agronomic practices are classified as feasible, although interpretation techniques for these purposes are not fully developed. The application areas and their estimated feasibilities are shown in table 4.

Feasible Applications

Reconnaissance surveys of major land uses, soils, surface water resources (including flooded areas), range conditions, and cropping practices utilizing satellite imagery are certain to yield considerable quantities of usable data. The first three data types have been sucessfully mapped or measured on low-resolution photography at the scale of 1:60,000 or smaller. These relatively low resolution requirements are well within the theoretical capabilities of photographic cameras operated from earth orbit. Moreover, the limited quantity of available space imagery indicates that reconnaissance photography of reasonably high quality is realistically achievable. In addition, significant gains are expected from the supplemental use of nonphotographic sensors.

The use of remote sensing for timely evaluation of range conditions and cropping practices has to date consisted mainly of experimentation with large-scale specialized images. Nevertheless, it seems certain that sequential observations of rangeland with photographic and other sensors will reveal tone and texture differences and changes which can be meaningfully related to density, vigor, and extent of range herbage. Similarly, many shape and tone characteristics associated with the planting, cultivation, and harvesting of crops should be identifiable. If maximum information is the goal, both range and agronomic surveys would place stringent demands on image quality. For

Table 4.--Potential applications of remote sensing from space platforms: estimated feasibility

Application area	Resolution requirements 1/		Interpretation capabilities		Estimated feasibility
	Photographic	Multispectral	Photographic	Multispectral	
Inventories of major land uses	Minimal	Minimal	Developed	Undeveloped	Feasible
Soils surveys	Minimal	Minimal	Developed	Undeveloped	Feasible
Water resources surveys	Minimal	Minimal	Developed	Undeveloped	Feasible
Bases for mapping	Minimal	Not applicable	Developed	Not applicable	Feasible
Range conditions surveys	Minimal	Minimal	Partially developed	Undeveloped	Feasible
Agronomic surveys	Minimal	Minimal	Partially developed	Undeveloped	Feasible
Crop species identification	Stringent	Minimal	Partially developed	Undeveloped	Possibly feasible
Crop vigor analysis	Minimal	Minimal	Partially developed	Undeveloped	Possibly feasible
Crop production estimates	Minimal	Minimal	Partially developed	Undeveloped	Possibly feasible
Livestock and wildlife surveys	Maximal	Maximal	Undeveloped	Undeveloped	Not feasible

1/ Resolution required to obtain usable or reconnaissance-type data relative to the maximum resolution theoretically obtainable. Resolution requirements for the detailed informational objectives associated with some specific applications within broad application areas will normally be greater than those indicated.

generalized information, however, neither has high resolution requirements since the units for interpretation are usually large.

Space photography, like conventional aerial photography, undoubtedly will be used as a base for mapping a variety of objects and conditions on the ground (particularly for many areas lacking adequate cartographic or photographic bases for certain purposes). However, the metric qualities practically and consistently attainable may not be equal to those of conventional photography.

Possibly Feasible Applications

Identification of crop species from space altitudes can be regarded as a distinct possibility, although it has been accomplished only experimentally or locally at low altitudes. Photographic sensors are not likely to prove generally adequate for this purpose because of the complex requirements evidenced in various experiments, particularly Colwell's work with cereal crop identification. Exceptions should occur in special situations, such as the use of near-infrared photography by Clair Hill and associates to identify rice.

The real hope for systematic identification of crop species is the multispectral approach under investigation at the Universities of Michigan, Purdue, and California, and at the Agriculture Experiment Station in Weslaco, Tex., which employs nonphotographic as well as photographic sensors. The relatively low resolution capabilities attributed to sensors operating at intervals over a broad range of the spectrum should not be a severe handicap. Ground resolution of a few tens or hundreds of feet appears adequate since the overall spectral response of large targets (fields of crops rather than individual plants) would be emphasized. Plants are not resolved individually, of course, even in low-altitude applications.

The potential application of remote sensing from space for crop vigor analysis must also be qualified. Variations or losses in crop vigor may be due to numerous factors, including disease, insects, mineral deficiencies and excesses, and adverse weather. In general, variations in vigor are rather strikingly imaged as tonal differences on selected photographs taken at low altitudes. On several occasions, in fact, a diseased condition in plants has been detected on near-infrared photographs before the condition was evident to ground observers. At least two factors, however, may limit the application of space platform sensors for this purpose. First, crop vigor analysis is dependent to some extent on crop identification, which (as noted above) is not clearly feasible. Second, while remote sensors are good indicators of loss of plant vigor, they are generally poor indicators of the causal agent.

Usable estimates of crop production appear feasible in special instances where crop identity is known or where crops can be identified indirectly. Such estimates should become generally achievable if the problem of crop identification is solved. Many factors affecting yield--site, agronomic practices, crop vigor, crop density or stand, and catastrophic events--can by interpreted at least in relative terms. Sample ground information could be used to refine the interpreted results. Acquisition of the necessary area data is not expected to be difficult.

Infeasible Applications

Detailed soils classification and mapping and censuses of livestock and wildlife appear infeasible from space altitudes. Detailed soils surveys have never been successfully conducted by aerial photography, while present research indicates that radar will yield only reconnaissance-type information. Reports on progress of the Michigan-Purdue study indicate that the multispectral system will have limited soil-discriminating capability.

From the purely theoretical point of view, inventories of livestock and wildlife may sometime be possible. From a practical standpoint, however, the existing obstacles appear insurmountable. First, under the most optimum conditions imaginable, severe restrictions on ground resolution would be imposed by scale alone. To illustrate, a focal length of 20 feet at a distance of 100 miles would yield a scale of 1:26,400, which is considerably smaller than those used with only limited success in experiments to date. An operational system would probably utilize a shorter focal length at greater distances with a consequently smaller scale. In any case, resolution could be increased only at the expense of wide-area coverage, thus offsetting one of the main advantages of a space platform and a particularly desirable feature in surveys of this type.

Another obstacle is the complex informational needs in livestock surveys. It is necessary or desirable to identify breed, age, sex, and other characteristics, as well as to distinguish various species. Even if resolution capabilities sufficient to detect domestic (or wild) animals become available, identifications and measurements of useful consistency most likely cannot be made from space altitudes.

Unclassified Applications

In view of the diverse nature of the data requirements, assignment of a feasibility rank to conservation surveys would appear to have little value. As reported in this study, the informational objectives in surveys of this type include data on soils, slopes, water resources, land use (including specific crops), yield, production, ownership characteristics, income, and the like. Moreover, these types of data in general must be mapped or otherwise precisely located geographically and often by individual farms as well. Some types of data, of course, are not at all susceptible to remote sensing.

Certain data types of interest in conservation surveys, e.g., major vegetation types, cropland, and drainage systems, have already been classed as feasible; that is, they are considered both identifiable and measurable from space altitudes. Other data in conservation surveys have been ranked as possibly feasible; and detailed soils classification, in particular, is regarded as infeasible.

CONCLUSIONS

The review of literature and current research on agricultural remote sensing leads to the following conclusions:

(1) Existing photographic sensors and photographic interpretation techniques are adequate to perform a variety of agricultural survey tasks from space platforms. Dependent upon the specific form and required degree of accuracy of the data, reconnaissance surveys of major land uses, soils, water bodies, range conditions, and cropping practices appear to be technically feasible.

(2) Crop species identification, crop vigor analysis, and crop production estimates of useful consistency and accuracy are not clearly feasible. It is probable, however, that useful interpretations of these types can be made in special situations utilizing photographic methods. Moreover, developing non-photographic sensing and interpretation capabilities may result in substantial informational gains, particularly when used in conjunction with photographic imagery.

(3) Detailed soils surveys and censuses of livestock appear unattainable from space altitudes because adequate resolution and interpretation techniques are lacking.

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